inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 5.1

ACOUSTIC PROTECTION OF BUILDINGS AGAINST AIRCRAFT EXTERNAL NOISE: CRITERIA AND DESIGN

L. Rocco, S. Sauro

*, Via Ghibellina 125, 50122, Firenze, Italy

Tel.: +39 55 218339 / Fax: +39 55 211441

Keywords:
BUILDINGS, NOISE CONTROL, AIRCRAFT NOISE

ABSTRACT

The noise produced by flying aircraft operations is formed by a succession of noise events emerging in a short span of time over the background noise; this type of time history is the main cause of interference with the night's rest because is responsible for awaking people. In order to assure sufficient acoustic protection for all those buildings in which people sleep the insulation requisite can no longer be based on the metric of noise exposure but instead on the metric of maximum level reached during the single event. The authors suggest a criteria to assess internal limit of the maximum level and a method to calculate the insulation requisite to make interior conditions ensuring an undisturbed night's rest.

1 - INTRODUCTION

The noise of the aircraft flying operations is an intermittent noise characterised by very wide fluctuations since it is formed by a succession of noise events emerging in a short span of time over the background noise reaching a maximum level very high then swiftly decreasing to the level of the background noise.
This type of time history is the main cause of interference with night's rest because is responsible for waking people during their sleep.
The typical temporal profile of an aircraft flight over is formed by an ascent ramp of the sound pressure level until to a maximum value followed by a descent ramp, without a plateau of appreciable length.
There are two different metrics for assessing the effects of noise on the people:

- the response of the people to noise is correlated with the exposure level of the total acoustic energy received during the noise event, normalized to a time $t_0 = 1$ s, expressed by A-weighted Single Event Sound Exposure Level L_{AE} and by the corresponding Continuous Equivalent Level L_{eqA}, defined by:

$$L_{AE}= 10\lg\left(1/t_0\right)\int_{t_1}^{t_2} 10^{L_{pA}(t)/10}dt = L_{eqA} + 10\lg\left[\left(t_2 - t_1\right)/t_0\right]$$

- where L_{pA} is the "instantaneous" value of A-weighted Sound Pressure Level and the times t_1 and t_2 individuate the instants of beginning and end of the noise event, the former is conventionally assumed as that in which the level reaches for the first time a value lower of 10 dB than the maximum and the latter as that in which the level becomes definitively smaller of 10 dB than the maximum;
- the response of the people to the noise is correlated to the maximum A-weighted Sound Pressure Level $L_{pA\ max}$ received during the noise event.

From the comparison of the exposure quantities obtained by a same temporal profile, using different integration times and exponential or linear averages in order to sample the "instantaneous" values, it results that, varying the integration time and the type of temporal average, it varies the position of instants t_1 and t_2 and consequently the conventional duration of the noise event; such variations

nevertheless are each other counterbalanced and the L_{AE} values are very closed between them and therefore the choice of the mode for sampling instantaneous values is not influential.
The maximum value $L_{pA\ max}$ reached at the top of the ascent ramp is on the contrary very much affected whether by the integration time constant or by the temporal average selected, therefore the integration time constant and the temporal average must be chosen univocally in order to have measures comparable with them and to define the interior limit values; the constant more generally used for the aircraft noise is that having the exponential average "SLOW".
On the Table 1 exposure levels L_{AE} and L_{eqA} measured with different modes of sampling the instantaneous values for a duration whether conventional or total and the maximum level $L_{pA\ max}$ measured with the same modes are compared for two different flight over operations; the position were above the flight path at the distance of 1000 m from the runway threshold.

LANDING OF DC 9 (Jet aircraft)					
Integration Constant	$t_2 - t_1$ *(s)*	$L_{AE\ (t2\ -\ t1)}$	$L_{AE(Total=11s)}$	$L_{pA\ max}$	$L_{eqA(Total=11s)}$
SLOW	5	101.8	101.9	97	91.5
FAST	3.19	101.6	101.9	99.3	91.5
LIN., 2 s	8	101.8	101.9	95.9	91.5
LIN, 250 ms	3.25	101.7	101.9	99.0	91.5
TAKE OFF OF FOKKER 50 (propeller aircraft)					
SLOW	7	95.4	95.6	89.8	84.5
FAST	5.3	95.4	95.6	90.6	84.5
LIN., 2 s	6	95.4	95.6	89.9	84.5
LIN, 250 ms	5.5	95.4	95.7	90.3	84.5

Table 1: Comparison of noise metrics.

Since the typical temporal noise profile of a flight operation is triangular, the maximum level $L_{pA\ max}$ reached can be evaluated from the L_{AE}, once known the conventional duration $t_2 - t_1$ of the noise event, by the following expression:

$$L_{pA\ MAX} = L_{AE} - 10\lg\left[(t_2 - t_1)\ /2\right]$$

While the effects on the people of continuous noises, even fluctuating are well correlated with the exposure metric levels as the L_{AE} and the L_{eqA}, on the other hand the effects of intermittent noises during the nightly rest time (22.00−07.00) are better correlated with the maximum level reached on the noise event $L_{pA\ max}$ together with the number N of the event occurred.
The critical interior noise levels regarding the interference with the night's rest induced by continuous noise as that of a vivid road traffic varies in literature within the range of equivalent levels $L_{eqA} = 37-40$ dBA; in case of intermittent noises, as that of aircrafts, the critical interior noise levels varies, depending on the events number, from $L_{pA\ max} = 53$ dBA for 2 events to $L_{pA\ max} = 47{,}5$ dBA for 30 events, according to the Table 2, deduced from ref. [1].

No of events (N) 22.00 – 07.00	2	3	4	5	6	7	8	9	10	20	30
$L_{pA\ max}$ (dBA)	53.0	50.5	49.6	49.0	48.7	48.5	48.3	48.2	48.0	47.8	47.5

Table 2: Interior maximum noise levels in order to avoid noise induced awakening [2].

The appliableness of the Table 2 is for short events lesser than 40 s, as they just are that produced by an aircraft over flight, and for a number of nightly event not more of 32; the maximum level values of Table 2 in any case are such as to protect from the awaking the 100% of the people in any sleep stage even the most sensitive (REM – Sleep) [1].

2 - CRITERIA

The need of to protect the sleep from the noise induced by aircraft traffic is imperative not only for all residential buildings, but even for hospitals, hotels and in general for all that building inside which the people can have the necessity to benefit by a quiet nightly rest.

The internal noise limit to define a proper protection of building in order to avoid interferences with nightly rest, must then be expressed in terms of level $L_{pA\ max}$; on the other hand, it is even necessary to do a choice if to assume a limit, as in the Table 2 depending by the number N of the nightly noise events or to assume a single value valid for whatever situation of nightly aircraft traffic.

Considering that the continuous increase of aircraft traffic leads to cancel improvements recently obtained with entrance on service of less noisy aircrafts and that acoustic protection of a building must be in any case designed in connection not with actual traffic, but with possible future traffic in airport saturation conditions, it seems to be right to state a single value of the admissible limit $L_{pA\ max}$ for building interior; taking into account measures tolerance and calculation accuracy it is suggested a limit $L_{pA\ max} = 45$ dBA for any number of noise events during the night.

3 - DESIGN

The external noise level necessary to determine building requirements of acoustical protection in a particular position on the area exposed to aircraft noise, must be the maximum level verifiable in that position during nightly flight operations; this maximum external level can be determined by a calculation model [2] or directly by measures on field.

Requirements of acoustical protection can be then expressed by means of Weighted Apparent Sound Reduction Index R'_w [3] or by Apparent Sound Reduction Index R' for octave or 1/3 octave frequency bands. Using the single number R'w, this can be calculated by following expression:

$$R'_w = L_{pA\ max(est)} - L_{pA\ max(int)} + 10\log(S/A)$$

where $L_{pA\ max\ (est)}$ is the maximum external level in free field, S (m^2) is the surface of the external element (façade or roof) as seen from interior and A (m^2) is the absorbing equivalent surface of the room.

The index R'_w for a façade, in which the windows are always the weakest barrier to noise and therefore the most determining, can be calculated with following approximate expression [4]:

$$R'_w = L_{pA\ max(est)} - L_{pA\ max(int)} + 5$$

Using this formula, in case of a landing of DC9 like that of Table 1, a building placed 1000 m from the runway threshold, in order to ensure adequate protection of nightly rest of people, should have an R'_w given by:

$$R'_w = 97 - 47 + 5 = 55\ \text{dB}$$

Using instead index R' for frequency bands [5], it is necessary to know the maximum external levels in free field for each frequency band and to state the internal limit levels for the same frequency bands; the firsts can be either measured in the field or calculated from external maximum level $L_{pA\ max\ (est)}$ and from a generalized aircraft noise spectrum (jet driven or propeller driven) as that of ref. [3] normalized to 0 dBA. The interior sound pressure limit level in dB for each frequency band corresponding to the limit level $L_{pA\ max\ (int)}$ can be in their turn calculated: the sound pressure level L_{pj} for the j-band is obtainable from the $L_{pA\ max\ (int)}$ using the following expression based on simplifying assumption of a uniform distribution of energy corresponding to interior maximum level over the frequency band considered

$$L_{pj(int)} = L_{pA\ max(int)} - 10\log N + C_j$$

where N is the number of bands and C_j is correction for A weighted curve corresponding to j-band changed of sign.

It is however suitable that to the value of the maximum internal level of the noisiest operation must be always associated even with the value of L_{AE} and duration of the event, in order to be able to verify the calculation and the measures developed for determination of the nightly level.

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